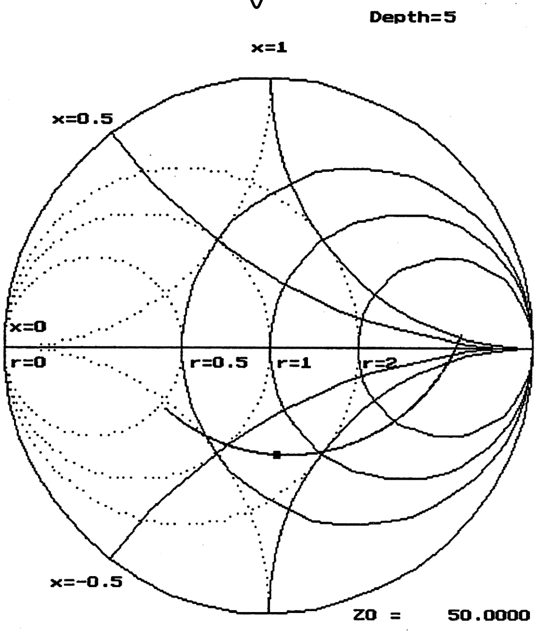
ARRL

MicroSmith

User's Guide



By Wes Hayward, W7ZOI

Contents

Chapter 1

Introduction

Welcome to *MicroSmith*. *MicroSmith* is a Smith® Chart simulation program for the IBM PC and compatible computers.[1] Smith® Chart is a registered trademark of Analog Instruments Company, PO Box 808, New Providence, NJ 07974, and is used with permission. The designation "Smith Chart" is used throughout the remainder of this guide. The Smith Chart was invented by Phillip H. Smith, and was originally described in cutout form as the Smith Radio Transmission-Line Calculator in *Electronics* for January 1939.

MicroSmith lets you perform Smith Chart calculations quickly and easily with the aid of a computer. The author originally wrote *MicroSmith* for personal use in professional applications, and still uses it extensively in that mode. However, the program has been modified for use by the engineering student and radio amateur.

The goal was to write the program so frequent reference to this guide is not necessary. The key to reaching this goal is a system of on-line Help screens. To illustrate impedance-matching applications, a dynamic tutorial exercise comes with the program.

MicroSmith requires an IBM-PC[2] computer, or compatible. The program will run on a computer with as little as 272K of installed RAM. Math coprocessors are not supported by *MicroSmith*, and are not required. The program supports VGA displays. *MicroSmith* will run on any operating system from DOS 5.0 and higher, or in a DOS window.

A Note about Copy Protection

The distribution disk for *MicroSmith* is not copy protected. This does not mean that the author or the ARRL advocate the free distribution of copies of the disk. We merely acknowledge that copy-protected disks are a pain, causing more fuss than they may justify. Our attitude is that this disk is like a book. If you buy a book, you might loan it to a friend to read and use. But it is not reasonable for your friend to copy the entire book. In a similar vein, we expect that you will not create situations where more than one person can use this program at a time. We have tried to price *MicroSmith* to be affordable, even by the student. We ask that you don't give copies away to others.

[1]Throughout this book, notes appear at the end of each chapter.

Comments, Questions, Suggestions and Software Support

The concepts that form the foundation of the Smith Chart are not covered in the program, the tutorial, or this guide. Instead, the emphasis is on application. You may want to retrieve your favorite text on transmission lines and study the fundamental concepts of the Smith Chart. (Basic information appears in other ARRL publications,[3,4] as does information for the advanced user.[5]) This program will then provide you with a convenient and enjoyable way to apply and extend the results of your reading.

Be sure to read the information contained in the README.DOC file on the distribution disk. This file contains information on any last-minute updates of the program. If you have a question or encounter problems with *MicroSmith*, please drop a note to the author. We also would like to hear from you if you find bugs or have suggestions for later program versions. We hope you enjoy using *MicroSmith*.

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The e-mail subject should be “MicroSmith.”

Notes

[1]IBM and PC are registered trademarks of International Business Machines.

[2]See Note 1.

[3]R. D. Straw, Ed., *The ARRL Antenna Book*, 18th edition, Chapter 28, “Smith Chart Calculations” (Newington, CT: ARRL, 1997).

[4]M. W. Maxwell, *Reflections—Transmission Lines and Antennas* (Newington, CT: ARRL, 1990). Out of print.

[5]W. N. Caron, *Antenna Impedance Matching* (Newington, CT: ARRL, 1989).

Chapter 2

Program Installation

MicroSmith is easy to install. The distribution disk contains several files that must be copied to your hard disk (the program will not run from the distribution CD-ROM). These files are found in the **Smith Chart** directory on the CD-ROM.

MicroSmith is easy to install. The distribution disk contains several files that must be copied to your hard disk (the program will not run from the distribution CD-ROM). These files are found in the **Smith Chart** directory on the CD-ROM.

Create a directory for *MicroSmith* on your hard disk, such as C:\SMITH. Copy the files from the CD to that directory.

SC_IRFD.EXE is the Smith Chart program itself.

SCTU.EXE is the tutorial.

LASTFILE.DAT is data for the last time the program was run.

README_IRFD.TXT contains late update information that may not appear in this book.

MicroSmith is a DOS program. However, it will run from the *Windows* environment via a DOS window. Start *Windows Explorer* and find the directory containing the program. *MicroSmith* is then run merely by double clicking it from *Explorer*. You can set up icons at this time to simplify the procedure.

Files can be named, saved, and recalled from the program. These files, which describe a circuit being impedance matched or evaluated, reside in the directory containing the program.

Chapter 4 describes the many features and tells how to use the program.

Printing *MicroSmith* from *Windows*

Printing from *Windows* is generally easy, although some subtle tricks are often needed to get the best results. When the *MicroSmith* screen is in the form that you want to print, merely press the **Print Screen** key. (You may have to press the key twice in some systems.) This then "captures" the screen as an image that is saved in the clipboard. You can then paste the screen capture into a *Windows* application and print it from there. You can do this with a word processor (for example Microsoft *Word*) or image editing program (for example, Microsoft *Paint*, which is found on most

Windows systems in the Accessories group).

The image pasted into the application from the clipboard uses white, blue and red traces and lettering on a black background. This will probably print as white traces and lettering on a black background if you don't have a color printer. The image may or may not print well on your printer. If it doesn't print well, the image must be inverted so that you have black traces and lettering on a white background. You can invert the image with Microsoft *Paint* or other image editing program. In *Paint*, the image can be changed to a white background by using **Invert Colors** from the **Image** menu. Other image editing software has a similar function.

Chapter 3

The Tutorial Program

To start the tutorial version of *MicroSmith*, make SMITH the current directory. From the DOS prompt type

SCTU **Enter**

The tutorial begins with introductory text, followed by a menu. Fig 3-1 shows this menu. By pressing the letter keys indicated, you will see how various networks or circuits may be used to attain a match between a source and a load.

At the bottom of the circuit menu you'll see the **A** key listed. This is an "all the above" command, causing the complete tutorial to be run. Alternatively, you can examine the specific examples listed in the menu. There are many places in the tutorial where you can either return to the menu by pressing **M** or exit the program by pressing **Esc**.

After you press a letter key, you'll see text information about the circuit you selected. Press a key to see a schematic diagram of the circuit to be analyzed. Again press a key and the Smith Chart appears. The component values appear on the screen and the resulting impedance is plotted on the chart.

With successive key presses, the value of one component changes, the change is shown on screen, and the new impedance is plotted. The "loop" action continues until the particular network has been illustrated. Fig 3-2 shows the Smith Chart display at the conclusion of the L-network design example.

```
              MENU -- MicroSmith, Smith Chart Tutorial
                 copyright, ARRL, 1992

        R         Simple Elements on the Smith Chart
        L         L-Network Design Example
        T         Transmission Lines on the Smith Chart
        M         Z Matching with Transmission Lines.
        W         Wideband Matching.
        N         Low Noise GaAs FET Amplifier Input Network.
        A         All of the above--the complete Tutorial.

        D         Adjust Delay.

        ESC       End the Tutorial Session.


        Press a key to indicate desired action.................
```

Fig 3-1—Main menu for the *MicroSmith* tutorial. Run the tutorial from the DOS prompt with the command SCTU Enter.

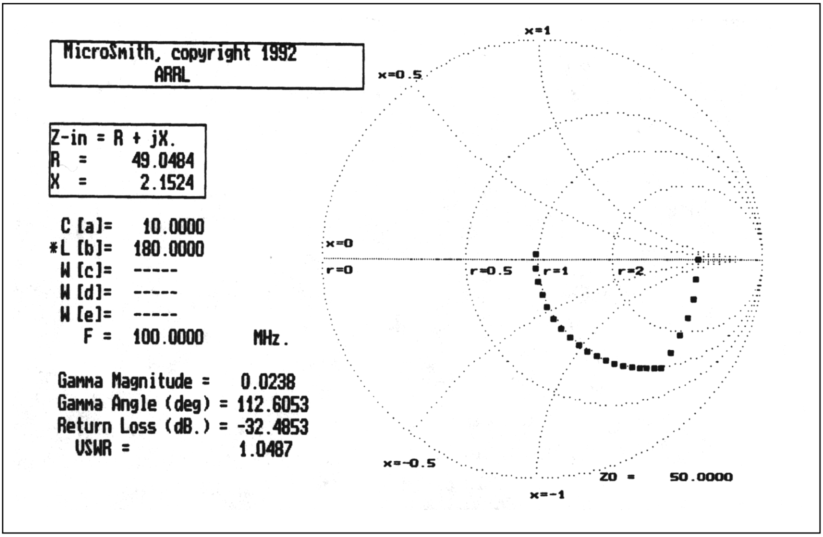

Fig 3-2—The tutorial display illustrating the results of matching with an L network.

If you are using a fast computer, the "looping" may be too quick to follow. The action can be slowed by inserting a delay in the loop. Do this when viewing the tutorial menu by pressing the **D** key, "Adjust Delay." A good value to try is 300.

After you've worked with *MicroSmith* for awhile, you may want to go back and run the tutorial program again. You can run the tutorial at any time from the DOS prompt by typing

SCTU **Enter**

Chapter 4

Using *MicroSmith*

As you use *MicroSmith* you will work by alternating between two graphics screens. One shows the Smith Chart itself with one or more impedance plots, as in Fig 4-1. The other is a schematic editor—a display showing a schematic diagram of the matching circuit, as in Fig 4-2. Switch between the two displays by pressing the **F9** function key. **F9** is a toggle key.

Perhaps the most important thing to remember at first is that on-line Help is always available from the Smith Chart display, Fig 4-1. A reminder in the upper right display corner shows that pressing the **F1** key starts the Help function. Once you are in the Help section, you will see a "Quick Help" display. After viewing that information you may press the **Esc** key (or about anything else) to return to the chart. Or you may press **M** (or **m**) to see "more." Then move between screens (pages) with the **PgUp** and **PgDn** keys. There are 12 screens of detailed help information.

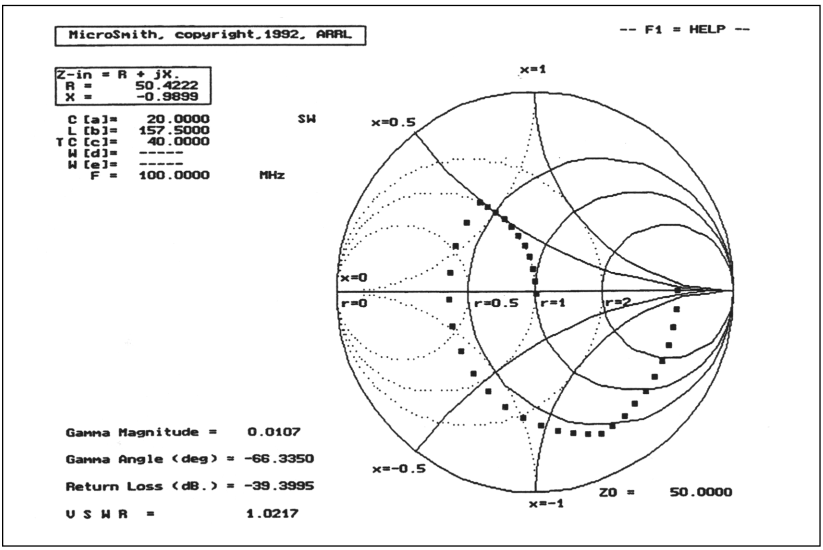

Fig 4-1—The Smith Chart display of *MicroSmith* after "tuning" the components of a pi network to match 300 Ω to 50 Ω. "Cursor trails" show the impedance transformations that result from applying each of the three components of the pi-network circuit of Fig 4-2.

The Smith Chart Display

Refer again to the Smith Chart display, Fig 4-1. The chart occupies most of the right-hand side of the display. The outer main circle of the chart is the "unit circle." The *MicroSmith* chart is a minimal one, with only a few of the circles of constant resistance and reactance presented. Experience indicates that the detailed, high-resolution grid appearing on the traditional paper chart is not needed with a computer program where calculated information is displayed in numeric form. The display with fewer lines is also drawn more quickly by the computer.

The characteristic impedance for the chart display appears in the bottom right corner. Although this is 50 Ω in most applications, other values may be selected. The tutorial program contains one example using a chart Z_0 of 300 Ω.

The chart is labeled with normalized values. For example, the horizontal line that bisects the unit circle is marked at the points where circles intersect it. These values, r = 0, r = 0.5, r = 1, and r = 2, refer to normalized resistances, where the normalization is with respect to the value of Z_0 used for the chart. The center of the usual 50-Ω chart, labeled with r = 1, has a denormalized value of R = 50 Ω. In general,

$$R = r \times Z_0$$

where

R = the denormalized value
r = the normalized value
Z_0 = chart characteristic impedance

Circle segments that intersect the edge of the unit circle are labeled with normalized reactances. For example, the point at the very top of the chart is marked with x = 1. An impedance at that point would have a reactance value of X = +50 Ω on a 50-Ω chart.

The upper left corner of the Smith Chart display contains a copyright notice. Immediately below this is an "impedance box" that shows the impedance of the present point on the chart.

The Schematic Display

Fig 4-2 shows the schematic display, obtained by pressing the **F9** function key from the Smith Chart screen. For illustration, a pi network is shown that matches a 300-Ω resistive load to a 50-Ω input. Up to five circuit components may be used in the network.

Pressing a letter key from **A** through **E** (or **a** through **e**) activates an editing menu for the associated circuit part. Fig 4-3 shows this menu for the capacitor, Part C of Fig 4-2. In the component editing menu you have the option of selecting one of seven component types. These are a capacitor (**C**), an inductor (**L**), a resistor (**R**), a reactance (**X**), a series transmis-

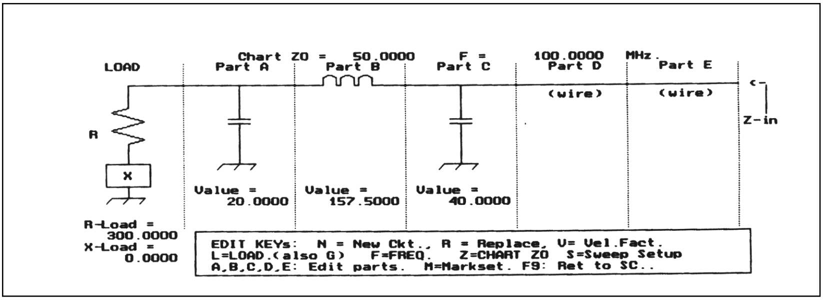

Fig 4-2—A pi network matches a 300-Ω resistive load to a 50-Ω input. Fig 4-1 shows the impedance transformations that take place through the network.

```
      Part       Code       Variables (units.)
--------------------------------------------------
  Capacitor      C     capacitance (picofarad)
  Inductor       L     inductance (nanohenry)
  Resistor       R     resistance  (ohms)
  Reactance      X     reactance (ohms)
  Series T-Line  T     Z0 (ohms), length (inches, mm, ft, or degrees)
  Stub T-Line    S     Z0 (ohms), length (inches, mm, ft, or degrees)
  Wire           W     Used for "passive" cell.
-------------------------------------------------------------------
  Series and Parallel connections are available for C, L, R, and X.
  The shunt STUB (S) may be either open or short circuited.
-------------------------------------------------------------------

Present Part:  C      Connection:  P
Part C    Press a Key to indicate desired Part Type:
Press S or P for Series or Parallel connection.
The unit of capacitance is pF.
Present value =    40.0000
Enter new value, or press ENTER to retain :

Present Tuning Step is     4.0000
Enter the TUNING STEP, or press ENTER to retain :
```

Fig 4-3—Component editing menu, obtained by a press of the letter key corresponding to the circuit part shown in Fig 4-2. The type of circuit component and its connection in the circuit (series or parallel) are selected from this menu. Other screens for supplemental data entry appear for some selections in this menu.

sion line (**T**), an open or shorted stub transmission line (**S**), or a wire connection (**W**). You may connect the C, L, R and X components in parallel or in series. You also select the component value and the tuning step size from this menu. Some selections from this menu cause other screens to appear where you enter supplemental information.

Tuning a Component

Below the impedance box on the Smith Chart display (Fig 4-1) is a list of the five component types and values. Upper-case letters signify the type of component. Following each of these letters is a bracketed lower-case letter, **a** through **e**.

The component designations in brackets are significant. Whenever you press the corresponding letter key, a through e, that component is labeled with a **T** just to the left of the value, showing that the marked component may be tuned. In Fig 4-1, Part C of the circuit has been marked. You may also select the part for tuning with the **PgUp** and **PgDn** keys. "Tuning" means that *MicroSmith* adjusts the value of the marked part in discrete steps. To tune a part, press the **up-arrow** or **down-arrow** keys respectively to increase or decrease the value. Set the tuning step size in the component editing menu. This is convenient to do during the entry of the initial circuit description. After tuning a part, the resulting new impedance is plotted on the chart and the corresponding value is updated in the impedance box.

There is a sixth letter, F (not in brackets), for frequency. Pressing **f** marks the frequency with a T and will allow the frequency to be incremented or decremented. Many traditional applications of the Smith Chart occur at a single frequency, but most modern applications relate to multiple-frequency plots. An example is the output screen of a network analyzer. Similar frequency sweeps are possible with *MicroSmith*.

It is possible to tune the characteristic impedance value of a transmission line while viewing the chart. This occurs with a "mode change," just like using the "2nd" or "alternate" keys on a calculator. Pressing the **Z** key activates the Z_0 tuning mode. A note appears in the upper right corner of the screen to tell you that you are in the Z_0-tune mode. If they exist, the Z_0 values related to those parts replace the a to e values. Then pressing the **a** through **e** keys, along with the **up-arrow** or **down-arrow** keys, will cause that Z_0 value to be tuned. The step for Z_0 tuning is the same for all transmission lines in the circuit.

The lower left portion of the chart display is reserved for user optional information, data that you may request by pressing special letter keys. Fig 4-1 shows a common choice. This selection shows the value for gamma (Γ). This is the reflection coefficient (magnitude and angle). Also shown with this selection is the return loss in dB, which is just 20 log Γ, and the related voltage standing wave ratio, VSWR.

Other data that can be shown in the lower left corner is the admittance related to an impedance, the Z, Y and F for a marker point that has been specified, the values for an equivalent series circuit having an impedance equal to that on the chart, the values for an equivalent parallel circuit with the impedance of the chart, and the lengths of all transmission lines in several length units. The letter keys you use to select these various information options are presented in Chapter 5, and are also defined in the on-line Help section.

The Sweep Function

MicroSmith also includes a Sweep function, activated by **F5**. The Sweep cannot be used until it has been set up from the schematic viewing section. Once the Sweep details have been set, pressing **F5** while viewing the chart will cause a selected parameter to be swept over the user defined range. The result is a curve on the screen. The Sweep can vary either frequency or a component value.

A variation of the Sweep function is Step and Sweep. This is a combination of two commands. Pressing the **+** key increments a tuned parameter, and then causes a Sweep to occur. Sweeps and tuning are usually applied to two different variables.

Another variation that may be used with the Sweep or the Step and Sweep options is the conjugate plot mode. This is useful for impedance mapping, but should be used with great care. It can be a conceptual trap if you do not have a firm understanding of the chart. The conjugate plot mode is discussed further on page 23.

A Brief Guided Tour

Several circuits are built into the program, accessed by pressing **F10**. Example 6 in the circuit library has a Sweep included, to illustrate the utility of the Sweep function. Let's use this as a short guided tour through *MicroSmith*.

Begin by entering SC from DOS. Immediately after the chart appears, press **F10**. Select item 6. A schematic diagram will then appear that shows a 300-Ω resistor as a load and an L network arranged to transform to a lower impedance. The L and C values are preset to 60 nH and 14 pF, respectively. The Sweep is preset in this example menu. Press **F9** to return to the Smith Chart display.

Once back to the chart, you will see that the present impedance is marked with a small square in the lower part of the chart. Press **F5**. This causes the capacitance to be varied from 0 to 20 pF in 0.5-pF steps. The Sweep is presented in *MicroSmith* as a solid-line curve. Now press **b**. This selects the inductor, component B, for tuning. Press the **up-arrow** key, causing the inductance to increase by 20 nH. After this is done, press **F5** again. A new curve is generated, slightly closer to the center of the chart. Continue the sequence of pressing the **up-arrow** and **F5** keys. Stop when one of the lines passes nearly through the center of the chart, marked r = 1. At this time you can press the **a** key, allowing the capacitor to be

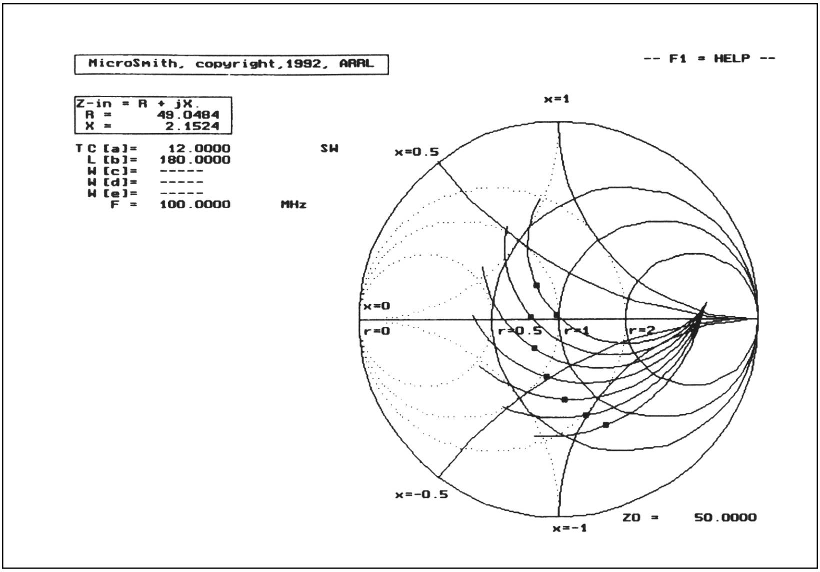

Fig 4-4—The display resulting from stepping and sweeping as described in the "Guided Tour" section of the text. The residual impedance-plot points (small black squares) were obtained by activating the "cursor trail" mode with the F2 key.

tuned in steps. Pressing the tuning arrow keys causes movement along the last sweep. Your final result should resemble Fig 4-4. Network tuning is completed within seconds!

Erase the screen with the **F8** key and then repeat the previous experiments with the **+** and the **–** keys. These keys activate the Step and Sweep function, where the tuned component value is first stepped up or down in value (**+** or **–** respectively), and then the Sweep is made.

Chapter 5

Key Commands for the Smith Chart

Chapter 4 mentions some of the keys that are active when the chart is being viewed. This chapter describes all the functions that are available in *MicroSmith* when viewing the Smith Chart. All of these parameters are listed in the on-line Help menus that are available on the CRT screen by pressing **F1** while viewing the chart. Case makes no difference; lower and upper case letters are accepted.

Esc—Pressing the **Escape** key is the way to exit the program. All is not lost if you should strike **Esc** by mistake. There are several chances to recover. Whenever you exit the program, the present circuit configuration is saved on disk in a file called LASTFILE.DAT. That file is automatically loaded when the program is started.

A, B, C, D, E—Pressing one of these keys selects one of the five circuit components for tuning. The value may then be tuned with the **up-arrow** and **down-arrow** keys. The size of the step is entered from the circuit editor. The step size can be doubled or halved with **F3** or **F4**, respectively. The components may also be selected with the **PgUp** and **PgDn** keys.

Up-Arrow and **Down-Arrow**—These keys increment or decrement the component value of the selected component. The Z_0 value for a transmission line or stub may be tuned if the transmission-line mode is first activated with **Z**.

F—Pressing **F** selects the frequency to be tuned with the **up-arrow** and **down-arrow** keys. The frequency step is set in the circuit editor, or can be altered with **F3** or **F4**.

G—This key causes the numeric value for gamma (Γ) to appear in the lower left portion of the chart display. Both magnitude and angle are shown. The return loss and VSWR are also displayed. Recall that the magnitude of Γ is the radius coordinate of a point on the chart. (At the chart edge, $|\Gamma| = 1$.) Return loss is merely 20 log $|\Gamma|$.

L—The **L** key refers to lines. Pressing **L** will show the lengths of the transmission lines and stubs in several different units. The default unit length is inches. Pressing **L** causes the lengths to be shown in feet, millimeters, and degrees at a design frequency. These units are also available during circuit construction.

M—Pressing **M** places a mark on the chart. This is a large plus sign, +. **M** also causes the coordinates related to the mark to be printed on the screen. As soon as another key is pressed, the mark data is erased, but the mark remains. The mark data includes Z, Y, and F for the mark, all in vector form. The mark is especially useful when transforming to an impedance other than the chart center, which is usually 50 +*j*0 Ω. For example, see the low-noise GaAs FET amplifier design in the tutorial. The data that defines the mark is entered from the schematic editor.

If you use the G option when in the schematic mode and when setting up the mark details, you may also enter a radius. The units are the same as normalized impedance. The result is that a circle centered around the + mark is plotted when you press M while viewing the chart. This may be used for a variety of applications. If the mark was at the center of the chart, the circle could be set up for any degree of mismatch desired, producing a circle like those generated by pressing **V**. Of even greater utility is the ability to plot a circle of constant gain. See the discussion in *Introduction to Radio Frequency Design*, ARRL, 1994. Other circles are often plotted on the Smith Chart. One type is a circle of constant noise figure. Another is a stability circle; this type will show a region that is stable (or perhaps unstable). The centers for stability circles are often outside the unit circle of the chart with a radius that causes the circle to sweep through the chart. These circles may still be plotted with *MicroSmith*. Stability circles and noise circles are covered by Gonzolez in *Microwave Transistor Amplifiers*, Prentice-Hall, 1983.

N—The **N** key allows a note to be placed on the chart. This is a line of text up to 50 characters long that you enter after pressing **Alt-N**. This could be a title, perhaps a circuit description, or even additional data. The information appears above the chart when you press N. The note or title is especially useful when you make printed copies to document your work.

Pressing **N** also causes the termination impedance to appear on the chart. This occurs only for a single-frequency termination, however.

P—The **P** key causes the parallel equivalent circuit related to a given impedance to be generated. That is, any complex impedance can be modeled as a resistance paralleled by a capacitor or inductor. Those values are calculated and then appear on the screen.

S—This key causes the series equivalent circuit related to an impedance to be generated with component values printed on the screen. The **P** and **S** keys are useful when trying to synthesize some matching networks. They are also handy when transforming between the two circuit topologies. The S or P data will vanish when another key is pressed.

V—Often it is desired to ensure that an impedance match will yield a VSWR of less than 1.5:1 or 2:1 over a specified frequency band. Pressing **V** from the chart display will cause these two circles to be plotted on screen.

Y—Pressing this key causes the admittance in millisiemens (1000/ohms, or millimhos) to be displayed. It is useful to turn this key on when tuning a network that contains a shunt element. The 20-millisiemen constant-conductance circle will intersect the center of a 50-Ω chart. The lines of constant conductance are added to the chart by pressing **Alt-F7**. See details below.

Z—Pressing **Z** allows the Z_0 of individual transmission lines to be tuned. If you always work with coaxial cable systems, you may not think in terms of having any control over the line impedance. However, the freedom is very useful when designing circuits with microstrip or other printed transmission lines. The Z_0 value for a line is loaded from the schematic editor. The step for Z_0 changes is the same for all lines in a circuit, but it can be doubled or halved with **F3** and **F4**. See comments in Chapter 4 regarding tuning. **Z** is a toggle command. Pressing **Z** while in the Z_0-tune mode returns the program to the normal mode.

F1—This is the on-line Help key. **F1** will always provide information to help you find your way around the program. The Help function is a multilevel command. Once you request help with **F1**, you have two choices. The screen that first appears is a quick reminder of what most of the commands do. Pressing almost any key will cause a quick return to the chart. However, pressing **M** or **m** provides access to 12 screens of more detailed information.

F2—The normal mode for graphing causes a small square to be printed on the chart at the position representing the impedance just calculated. Just before this occurs, the previous point is erased. No "trail" is left on the screen. However, if you wish to leave a trail of all the impedance points on the screen, press **F2**. This is a toggle; pressing **F2** again causes erasure.

F3—This key doubles the step size associated with a tuned element. Recall that pressing **a** through **f** selects an element or the frequency to be tuned. The increment size is entered from the circuit editor. The value of the step of the selected component is doubled by pressing **F3**. Only that step is doubled; the others are unchanged, with the exception of Z_0 tuning. See **Z** above.

F4—This key divides a step size by 2. The action is the opposite of the **F3** key described above. Impedance matching usually starts with large steps. **F4** then decreases the step to "move in" on a near-perfect impedance match.

F5—Pressing **F5** causes a Sweep of a component or frequency to occur. This program feature is extremely useful when tuning a matching network. See also + and -. The Sweep function allows the value of a part to be swept over a range. Assume for illustration that you wish to tune an L network containing a shunt capacitor and a series inductor. Set the Sweep up to vary the C from 0 to 20 pF. Pressing **F5** while viewing the chart causes this variation to occur. That is, the capacitor assumes values from 0 to 20 pF and a corresponding curve is drawn on the screen. An ideal way to tune this network begins by pressing the key related to the series inductor. The inductor value may then be stepped with the **up-arrow** and **down-arrow** keys. After each step, press **F5** to show the line of impedances available from a 0 to 20-pF tuning of the capacitor.

The Sweep function occurs in a way that keeps the existing value. Assume in the previous example that the capacitor is set up to be 10 pF with a tuning step of 2 pF. Pressing **F5** causes the 10-pF value to be momentarily set aside. The 0 to 20-pF variation occurs and a curve is drawn on the chart. It makes no difference which component is selected for tuning at that time. The Sweep function applies to only one part. After the curve is plotted, the capacitor value returns to the original 10-pF value. The capacitor can still be tuned with the normal **up-arrow** and **down-arrow** keys. The component that is set up to be swept is marked with SW to the right of the component value.

F6—**F6** allows you to import data from files generated by other programs including SPICE, or from the keyboard. Hence, if you have measured or calculated data, you can enter it into *MicroSmith* and display it on the screen. The imported data is displayed with the **Alt-G** key combination. Details are integrated into the Help/More screen, page 10. Also see Chapter 8 for additional information and examples.

Data imported with **F6** may only be viewed. You can also import data for use in calculations. You do this with frequency-dependent terminations, discussed under the **G** key in Chapter 6.

F7—This key is a cleanup aid. When you press **F7**, a new chart is drawn on top of that present. Any lines that had been erased by the moving impedance mark are replaced.

F8—This is another cleanup feature. Pressing **F8** causes the chart to be erased and a new one to be generated. Be careful with **F8**; previously displayed impedance marks and sweeps are erased.

F9—This key is the route to the schematic editor and back. Pressing **F9** erases the Smith Chart and replaces it with a circuit diagram. Circuit editing and construction is described in Chapter 6. The schematic screen appears quickly, allowing you to move between it and the Smith Chart display with ease. When you are finished with the editor, press **F9** again to return to the Smith Chart.

F10—This key is a starting point when you initially enter **SC**. Pressing **F10** causes the menu of Fig 5-1 to appear. This menu shows a library of available circuits. Most circuits are fairly simple, providing a starting point for circuit construction. A listing of library elements is avail-

```
        LIBRARY OF CIRCUITS FOR MICROSMITH.
        ==================================

    Most circuits use 100 MHz as the default frequency.

   Ckt      Load          Part      Part      Part      Part      Part
   Nr.      R     X       A         B         C         D         E
   -------------------------------------------------------------------
   0.    (Begin with 50+j0 load and no components.)
   1.       0     0       R(Ser)    X(Ser)    ---       ---       ---
   2.       25    0       T         ---       ---       ---       ---
   3.       50    0       X(ser)    X(par)    ---       ---       ---
   4.       100   0       L(ser)    ---       ---       ---       ---
   5.       100   0       C(ser)    ---       ---       ---       ---
   6.       300   0       C(par)    L(ser)    ---       ---       ---
   7.       70    0       L(ser)    C(ser)    T (antenna model)   ---
   99.     (Keep present circuit without change.
   -------------------------------------------------------------------
   Enter Ckt Nr.
```

Fig 5-1—Pressing F10 while viewing the Smith Chart calls this library of circuits menu. Eight circuit arrangements are available to use as a starting point for your own design. If you press F10 accidentally, entering 99 here allows you to return to the circuit you were working with.

able in the Help section, accessed with **F1**, followed by the "More" key **M**.

After you make a choice from the library menu, the corresponding circuit is loaded into memory and the schematic is displayed. You can then view and alter the circuit details. Don't forget to check and, if required, change the frequency.

F10, circuit 6, is especially useful when learning how to use the Sweep mode, as described in the "Guided Tour" in Chapter 4. Of special interest to the radio amateur is circuit 7 in the library. This entry builds an electrical model for a center-fed dipole antenna. The antenna is modeled as a 70-Ω resistor in series with a series-tuned circuit. The inductance value is L = 150/f, where L is in microhenrys and f is in MHz. The library element includes a 50-Ω transmission line, initially set to zero length. Changing the line length illustrates the way the length of a line will alter the impedance presented by an antenna system. An automatic frequency sweep is set up with the antenna model, producing network-analyzer-like results.

***Alt*- Keys**—These keys are a combination of the **Alt** key and the named key. Press the named key while you hold the **Alt** key down. For example **Alt-F3** indicates you should hold down the **Alt** key while pressing the **F3** key.

Alt-B and **Alt-C**—Pressing **Alt-B** causes a change of colors. What had been red, green or yellow on a color monitor is now a uniform white-on-black. This feature is useful for hard-copy graphics generation. Many print-screen utilities attempt to treat colors with halftones. As a result, a light red line is sometimes difficult to see on the output from a printer. A primary example is with the program CAPTURE.COM, a utility that comes with Microsoft Word. It allows a screen of graphic information to be "captured" and imported into a document. The printed results are most impressive when the Smith Charts are a heavy white on a black background; they are not so good when the colors are retained. The reverse key combination is **Alt-C**; this restores a color display.

Alt-D is a toggle command to make the chart dim or bright. The dim display uses dots to print the chart, while the bright one has solid lines. Both are in color if your monitor is a color EGA or VGA. The dot format is more useful for the user with a monochrome CGA or a Hercules display system. The lines are nicer when the high resolution color display format is available.

Alt-G—This combination of keys prints gamma data that has been imported. The files are moved into *MicroSmith* with the **F6** key, as described above.

Alt-J—This option may be called only after activating the **Alt-Z** key combination. See the information below.

Alt-N—This key combination allows you to enter a line of information from the keyboard, a string. This string, up to 50 characters in length, appears on the chart when you press **N**.

Alt-P—Pressing this combination causes the screen display to be printed on an Epson or Epson-like printer connected to the parallel printer port. The resolution is modest, but useful, and the printing time is reasonable. Geometry difficulties are easily fixed with **Alt-V**.

Alt-R and **Alt-S**—These sequences respectively retrieve and save circuit designs in disk files. The need to describe a circuit each time you enter the program can be frustrating. Often the last circuit that you used will be one that you need again. *MicroSmith* stores a circuit and all related parameters on disk. The data can be quickly retrieved while viewing the chart.

When viewing the Smith Chart, press **Alt-S** to store or save the present circuit. You must supply a name for the file. (If you inadvertently press Alt-S, merely press **Enter** to return to the Smith Chart display.) The circuit is then stored in an ASCII file. The stored circuit is now available the next time you use *MicroSmith*. Recall the circuit with **Alt-R**. Again, you will be asked for a file name. Both **Alt-S** and **Alt-R** show a list of circuit files in the directory containing SC. The files stored on disk have an extension of DAT. An example is DIPANT.DAT. The program attaches the DAT extension. You should not include an extension when naming files.

Exiting the program causes the present circuit to be saved in a file called LASTFILE.DAT. This file is automatically loaded when the program is next called. Start a completely new circuit by pressing **F9**, followed by **N**.

Alt-V—This key combination distorts the display on the screen in the vertical dimension in order to generate a round chart on a printer. You will be asked to enter a geometry factor near 1. The largest value allowed is 1.13, with values less than one being more commonly used. Values in the range of 0.85 work nicely with many systems. If you merely press **Enter** when asked for an input, the value used is the reciprocal of the last one entered. Hence, a repeat use of **Alt-V** returns the screen to the previous condition.

Alt-Z—This key sequence is an entry password, selecting special and rather subtle features. Pressing **Alt-Z** first produces a couple of beeps and a warning message, and then allows you to return to the Smith Chart display. But now you have the freedom to choose some additional options. Even the details in the Help screens change after **Alt-Z** is pressed. **Alt-Z** is a toggle; pressing it a second time takes you back to the normal "protected" format.

Alt-Z, followed by **Alt-J**—This is the entrance to the conjugate plot mode. Pressing this key combination produces a warning in the upper right screen corner indicating that the plotted data is not the actual impedance. Instead, the plot is the complex conjugate of that impedance. This is useful for a variety of network analysis problems. One network of particular interest is the traditional radio amateur Transmatch or antenna tuner. This matching network is connected between a transmitter and a transmission line. The function is to transform a mismatched line-input impedance to, usually, 50 Ω, which becomes the load for the transmitter. If the network is placed "backwards" with a 50-Ω termination, the impedance "seen" while looking into the resulting circuit is not the line impedance. Rather, it is the complex conjugate. Hence, by using the conjugate mode with *MicroSmith*, you can plot a family of curves (with the Step and Sweep function) that are the impedances you can "reach" with your Transmatch. The conjugate plot mode should be used with care; if you don't understand what is happening, the results can be quite confusing.

Alt-Z, followed by **Ctrl-F10**—This sequence produces random variations of component values. A network is often designed to be tunable for matching a variety of impedances. A double-stub tuner is one example. Another is the Transmatch used for antenna matching by radio amateurs. You may wish to see what the results are when one or several component values are allowed to vary randomly over a specified range. This "poor man's Monte Carlo analysis" is accessed by pressing the

F10 key while holding down the **Ctrl** key, but is available only after the **Alt-Z** combination has been activated. Each variable element in the circuit is characterized by a lower limit and a range. Once you enter the data, the program returns to the Smith Chart and a random variation occurs with the tunable elements. The resulting impedance is plotted, and the procedure is repeated. This happens many times before the program returns to the normal mode.

This feature is menu driven. However, be cautious. Once an analysis has started, there is no provision for escape until it is finished. Another method of examining the range of tunable networks is through the Sweep or the Step and Sweep functions.

Alt-F3—Pressing these keys causes a menu to appear in the upper left corner of the chart, showing the tuning steps presently active. The information disappears when any other key is pressed.

Alt-F7—This key combination causes lines of constant conductance to appear over part of the chart. These are especially useful when you are tuning elements that are shunt connected. The lines appear as dots, and are in green on EGA and VGA color monitors. This is in keeping with the multicolor charts that are available from Analog Instruments Co, founded by the late Phillip Smith, originator of the Smith Chart.[6] The constant conductance lines are automatic when a VGA system is in use.

+ and **–** —These keys activate the Step and Sweep function. Recall that the **up-arrow** and **down-arrow** keys step the value of a selected component. **F5** sweeps a value of a component. The swept component is not generally the same one that is stepped. The **+** and **–** keys activate a double action: Pressing **+** is identical to pushing **up-arrow**, followed by pressing **F5**. Pressing the **–** key is the same as down-arrow followed by **F5**. The Step and Sweep function allows an L network to be tuned to a desired impedance in a few seconds.

Ctrl-F10—This option may be called only after activating the **Alt-Z** key combination. See the information above.

Note

[6]Analog Instrument Co, PO Box 808, New Providence, NJ 07974.

Chapter 6

Key Commands to Construct and Edit Circuits

Pressing **F9** while viewing the Smith Chart erases the chart and displays a schematic diagram of the present circuit. Pressing **F9** again causes circuit erasure and the reappearance of the Smith Chart. Circuit editing is available only when the schematic is being viewed, and is detailed in this chapter.

Fig 6-1 illustrates the Schematic Editor screen. The schematic shows the terminating load at the left and the five components. This screen has a list of Edit operations in the box at the bottom. The keys used for editing or circuit construction are listed below.

A, **B**, **C**, **D**, **E**—Pressing any of these keys allows the corresponding component to be edited. When you press one of these keys, the display is erased and replaced with text questions. Chapter 7 contains information on the key commands for various component types.

F—Pressing **F** allows the frequency to be edited. The present frequency and the frequency step, both in MHz, may be set.

G, **L**—Pressing either the **G** or **L** keys allows network-termination (load) data to be entered. You may enter the data as either a gamma reflection coefficient F, or as a complex impedance Z. When you press **G** or **L**, the display is replaced with text. You are asked to specify the nature of the termination. Do this by entering the number of frequencies you want to use to describe the load. If you enter **1**, the termination will be a constant impedance for all frequencies. This is the usual format for

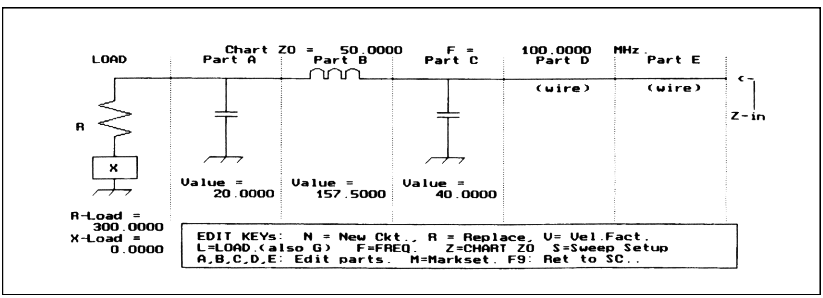

Fig 6-1—The display screen for the Schematic Editor. The editor function keys are summarized in the box beneath the diagram. The on-line Help screens contain additional information.

simple problems. After you enter the number of frequencies, you are asked to give the form of termination that you will use, G for gamma or L for impedance.

If you select the single-frequency option, you next enter the termination in the G or L format. The gamma form asks for data as a reflection coefficient magnitude and angle in degrees. The impedance form asks for the load as a series resistance and reactance.

Much greater flexibility is available if you specify a multiple-frequency input form. In this case, you are asked to enter the data as a table with a set of frequencies in megahertz. *MicroSmith* saves (and uses) the data as a table of polar gamma values. You may, however, enter the data points in either gamma or impedance form. The data should be entered in ascending order by frequency. This feature is discussed in much more detail in Chapter 8, where several examples are given.

M—This key loads the data for the Mark impedance. This is a particular impedance that you can later mark on the Smith Chart. The Mark is useful when adjusting an impedance-transforming network. Consider an example: A two-stage amplifier requires a matching network between stages. The output impedance of the first stage is 250 – *j*40 Ω. The input impedance of the second stage is 10 – *j*10 Ω. You could design the network by setting the load to 10 – *j*10 with a Mark set to appear at Z = 250 + *j*40. (This is the complex conjugate of the first-stage output impedance.) Enter a two-element L network at elements A and B. Then when you view the chart, press **M** to place the Mark on the chart, and tune the two components until the input impedance is on top of the mark. A Z_{in} value equal to the mark impedance indicates that the desired impedance match has been realized.

When you press **M** while in the Schematic Editor, you will be asked the form of the data to be entered. Press **Z** or **G** to tell if you will enter impedance or Γ data. Then enter the numeric information. If you press **G**, you enter a Γ value and then specify a circle radius. This radius value plots a circle centered about the specified mark. See the information under the **M** key in Chapter 5.

N—Pressing **N** initializes the program for a new circuit. The existing circuit is erased and replaced with wires in all five component slots, A through E. The load is set to 50 + *j*0 Ω and the frequency is set to 100 MHz. The chart Z_0 is set to 50 Ω.

R—Replace a component. An impedance-matching network design begins in *MicroSmith* by defining the network from the Schematic Editor. The components are then varied by tuning while viewing the chart. Some components are more convenient than others if the parts are allowed to take on negative values. Both the shunt inductor and the series capacitor present problems. A change of sign for either results in a discontinuity in the chart plot. However, the series inductor and the shunt capacitor are both well behaved, producing a smooth plot on the Smith Chart as the sign is changed.

Accordingly, *MicroSmith* is enhanced with a component replacement feature. This function is part of the Schematic Editor. When viewing the schematic, the "replace" operation is initiated by pressing **R**. This causes any negative inductors to be replaced with positive capacitors, and any negative capacitors to be replaced with positive inductors. Additionally, all reactance values, component X in the component menu, are replaced with the appropriate L or C values.

The suggested method for using *MicroSmith* for impedance matching with L-C networks is to construct a circuit with only series inductors and shunt capacitors. Then adjust the values to realize the desired transformations. Use both positive and negative values, as this allows any point within the unit circle to be reached with a two-element network. After tuning is done at a single frequency, press **F9** to return to the Schematic Editor, and then press **R**. The negative values are converted.

S—Pressing **S** programs the Sweep data. You first choose the component to be swept, A through E, or F for frequency. Then at the prompts enter the first and last values. A default step of the difference divided by 25 is available by entering 0. Alternatively, enter your desired Sweep step value. See Chapter 4 for additional information regarding the Sweep function.

V—The default velocity factor for transmission lines is 1. However, you may change this value by pressing **V**. The velocity factor, if different from unity, will then be displayed with the Smith Chart. This is especially useful for microstrip designs.

Z—This key sets the chart Z_0. The default value is 50 Ω, as the typical application uses a 50-Ω chart. However, there is nothing sacred about 50 Ω. All of the concepts of the Smith Chart apply equally when the value chosen for Z_0 is anything else, 1000 Ω for example. The value for Z_0 must be nonreactive in *MicroSmith*.

Chapter 7

Key Commands for Component Types

Just a few component types are treated in *MicroSmith*. The selection is extensive enough to allow almost-any practical circuit to be described and analyzed.

From the Schematic Editor, pressing letter keys from **a** through **e** brings text questions to the screen. The menu in the upper part of Fig 7-1 first appears, and the existing component and its connection are outlined. The questions follow. If you wish to keep the designations shown, merely press the **Enter** key in response to the questions. Alternatively, you may press letter keys to indicate your choice of component type and connection. These choices are presented in an on-screen menu, and are outlined below.

You must define the connection after a component type is selected. This is either parallel or series (**P** or **S**) for a simple part such as a capacitor or inductor. For stub transmission lines it will be **O** or **S**, indicating an open- or short-circuited stub.

Following the data that defines the connection, you must provide component values. The existing value is shown; merely press **Enter** to keep

```
      Part       Code       Variables (units.)
--------------------------------------------------
   Capacitor       C     capacitance (picofarad)
   Inductor        L     inductance (nanohenry)
   Resistor        R     resistance  (ohms)
   Reactance       X     reactance (ohms)
   Series T-Line   T     Z0 (ohms), length (inches, mm, ft, or degrees)
   Stub T-Line     S     Z0 (ohms), length (inches, mm, ft, or degrees)
   Wire            W     Used for "passive" cell.
-------------------------------------------------------------------
   Series and Parallel connections are available for C, L, R, and X.
   The shunt STUB (S) may be either open or short circuited.
-------------------------------------------------------------------

 Present Part:  C      Connection:  P
 Part C    Press a Key to indicate desired Part Type:
 Press S or P for Series or Parallel connection.
 The unit of capacitance is pF.
 Present value =    40.0000
 Enter new value, or press ENTER to retain :

 Present Tuning Step is     4.0000
 Enter the TUNING STEP, or press ENTER to retain :
```

Fig 7-1—This menu for editing component parameters appears when you press a letter key from a through e from the Schematic Editor screen. In this menu you define the component.

that value. If the part is a section of transmission line, you must enter the Z for the line. There is no requirement to have this the same as the Z_0 value for the chart. This is an example of a situation where a computer-based Smith Chart is more versatile and general than a printed chart.

Next you are asked for the value of the step to use when tuning a part. This choice is not critical, for you can double or halve the value during tuning and Smith Chart display with the **F3** and **F4** keys.

The preceding paragraphs give an overall summary of the schematic editing procedure. Information about each type of *MicroSmith*'s circuit parts follows.

C—This is for a capacitor. The connections are series or parallel, and the unit is the picofarad. Capacitors are assumed to be lossless in *MicroSmith*.

L—Pressing **L** enters an inductor as a series or parallel element. The unit used in *MicroSmith* is the nanohenry; 1000 nanohenrys equals 1 microhenry. *MicroSmith* inductors are lossless with infinite unloaded Q.

R—Pressing **R** when a part is to be defined enters a resistor. It may be either series or parallel connected, and has the units of ohms.

S—Pressing **S** inserts a stub transmission line. You are asked for the Z_0 value for the line. This may be a value different from the chart Z_0, and it need not be the same as other transmission lines that may exist in the circuit. (However, the velocity factor of all lines in the circuit must be the same.) Indicate if the line is open or short-circuited at the end away from the main signal path. The line length has the default unit of inches. Alternatively, you may specify the length in feet, millimeters, or electrical degrees at the design frequency. Lengths in these units are available by pressing **L** when viewing the chart. The line-length step value is also requested.

T—Pressing **T** for a component inserts a series-connected transmission line. You must define the Z_0 value. The line length is specified in the units described for S above. The series-connected stub form is not included in *MicroSmith*.

W—Pressing **W** enters a piece of wire as the element. The beginning circuit has five cascaded pieces of wire. These elements have no time delay; as such, they do not represent a real piece of wire. Instead, they are just an ideal series short circuit.

The *wire* has a special significance that is not immediately apparent. Assume that a component has already been defined as, for example, a series capacitor. The value has been determined by tuning while watching the chart. Now you wish to see the results without the capacitor. Go to the circuit editor and replace the capacitor with a wire, and then return to the chart to examine the impedance. Once this is done, you can return to the circuit editor and redefine the component as a capacitor. *MicroSmith* remembers the value, connection, and step size, and all are the same as they were before the component was temporarily redefined as a wire.

X—Pressing **X** selects a reactance. *MicroSmith* takes this reactance to be independent of frequency, which is difficult in practice. Still, it is a useful element in some applications.

Chapter 8

Advanced Applications

This chapter relates to some advanced uses of *MicroSmith*. Much of the following discussion assumes that the reader is familiar with the computer programs SPICE and ELNEC. References are provided for additional reading. The use of SPICE and ELNEC to illustrate the features of *MicroSmith* is not to be considered an endorsement by the ARRL.

SPICE is a general-purpose circuit analysis program. A circuit is described by a nodal net list and descriptions of circuit-element parameters. SPICE then allows frequency sweeps and transient analysis to be performed. Nonlinear details are included in SPICE, allowing evaluation of many practical and interesting circuits. (See the book by Walter Banzhaf, *Computer-Aided Circuit Analysis Using SPICE*, Prentice-Hall, 1989. Paul Tuinenga has prepared a similar text offered by MicroSim, *SPICE: A Guide to Circuit Simulation and Analysis Using PSPICE*, 2nd edition, Prentice-Hall, 1992.) Although the greatest feature of SPICE is the ability to do nonlinear analyses, it is also capable of fast and accurate linear analyses. The linear sweeps provide the data of interest for *MicroSmith*.

The author has used both PSPICE from MicroSim and IsSpice from Intusoft. PSPICE has a wonderful demo/student version that is excellent for small circuits. The complete SPICE engine in IsSpice costs less than $100 at the time of this writing; both programs are highly recommended. Advertisements for both companies appear in the electronics trade journals.

Another example for the radio amateur is ELNEC, an antenna design program using finite-element analysis methods. ELNEC is marketed by Roy Lewallen, W7EL, of Beaverton, Oregon. This program calculates radiation patterns and gains for antennas constructed of wires or tubing. It also calculates antenna terminal impedances. Placing this data on a Smith Chart represents the ideal beginning for impedance matching. ELNEC is advertised in the pages of *QST*, *CQ* and *Communications Quarterly*. The two programs mentioned are merely examples. As a *MicroSmith* user, you may have a program that generates impedance or reflection coefficient information. Often it is advantageous to use this data in *MicroSmith*.

Moving Data into *MicroSmith*

Begin importing data for viewing in *MicroSmith* with the function key **F6**. With **F6**, you are given the choice of reading external data from a

```
        Freq, MHz.   Magnitude    Angle, deg.
1        10.000       0.890      -21.440
2        20.000       0.866      -41.280
3        30.000       0.835      -58.770
4        40.000       0.805      -73.630
5        50.000       0.778      -86.040
6        60.000       0.757      -96.340
7        70.000       0.740      -104.900
8        80.000       0.726      -112.100
9        90.000       0.715      -118.100
10       100.000       0.707      -123.300
11       110.000       0.700      -127.700
12       120.000       0.694      -131.500
13       130.000       0.690      -134.800
14       140.000       0.686      -137.700
15       150.000       0.683      -140.300
Enter N for the value to change:
                 Enter 0 if there are no changes.
```

Fig 8-1—Screen display for entering or editing external data into *MicroSmith*.

disk file or entering information from the keyboard. Press **T** if you want to type data into a table. Up to 15 entries may be entered and edited, using the table illustrated in Fig 8-1. The entries contain 15 sets of three parameters. The first in the set is a frequency. This is generally in megahertz. The second and third elements are the magnitude and phase of the reflection coefficient in polar form. This data form was chosen because it is the form of scattering parameters.

Data may be imported from a "gamma" file, a text file located in the same directory that contains *MicroSmith*. The file should be in ASCII form, and may be created with a word processor or text editor. The extension GAM must be included with the filename. Enter each data element by itself on a single line, followed by a carriage return (use the **Enter** key while in your editor program). The first file element is the characteristic impedance, Z_0, usually 50 Ω. When a file is read, the Z_0 value in the file will dictate that of the chart. The next three elements in the file are the values of frequency, E magnitude, and F angle in degrees. Continue this sequence of three data elements for all data you want to include in the file. Be sure to follow the very last data entry with a carriage return, and be sure the file has an extension of GAM. Read the file from *MicroSmith* by pressing **F6** from the chart, followed by **D**. You may edit the first 15 elements of the file from the editor in *MicroSmith*. However, up to 200 points are allowed in the data file. Some example gamma files are included on the *MicroSmith* distribution disk. These are discussed later.

Viewing Imported Data

A return to the chart occurs after you enter the data. Plot the data by pressing **Alt-G**. The frequency range is displayed in the lower right corner of the screen, and the impedance data is presented as a group of small dots. The dots are in color if you have a color monitor. The colors correspond to the standard EGA color numbers with 1 = blue, 2 = green, etc. In this way the colors follow the number of the element in the file.

ELNEC Application of Data Importing

An exercise is suggested here to present ELNEC data to *MicroSmith*. If you have ELNEC, run the program with the BYDIPOLE example that Lewallen includes. This is a simple 14-MHz backyard half-wave dipole. Run the program at several different frequencies, noting the input impedance for each. (Instead of running ELNEC, you may prefer to use the data of Table 8-1.)

Now you must convert the data to reflection coefficient form. This can be done with *MicroSmith*, as described on page 36. You can manually enter the gamma data with **F6** followed by **T**, or you could generate a text file with an editor. If you generate a text file, name it BYDIPOLE.GAM.

While viewing the Smith Chart, plot the data for viewing with the **Alt-G** keys. Your final result should look like that of Fig 8-2.

As a matter of interest, compare the ELNEC data with the simple antenna model built into *MicroSmith*. Do this by pressing **F10** and selecting no. 7. Enter the dipole resonant frequency as 14.5 MHz. (Although not exact, that is close enough for this purpose.) Then press **F9** to view the Smith Chart. Reread the BYDIPOLE.GAM file or enter the table data again, using **F6**. Press **Alt-G** to view the imported ELNEC impedance data, and then **F5** to cause a frequency sweep of the antenna model. This comparison may give you some ideas on how to synthesize an antenna with discrete circuit parts, and *MicroSmith* will quickly tell you how accurate your synthesis is.

Table 8
Calculated Feed-Point Impedances of the Backyard Dipole

Freq, MHz	*R*	*jX*
14.0	76.6465	–46.6271
14.2	78.6232	–27.3934
14.4	80.5958	–81.1377
14.6	82.5692	11.1659

CONVERTING IMPEDANCE VALUES TO REFLECTION COEFFICIENT

An impedance may easily be converted to reflection coefficient (gamma) data in MicroSmith by performing the following steps:

1. Go to the schematic editor display and press **N**, creating a direct connection between the input and the load.
2. Press **L Enter L**. Then, enter the resistance and equivalent series reactance (j term) of the impedance to be converted. Include a minus sign for the reactance if it is capacitive. When you complete the impedance data entry, you will be returned to the schematic display.
3. Press **G Enter G**. The Gamma magnitude and angle are presented. Press **Enter** twice to get back to the schematic editor for further conversions.

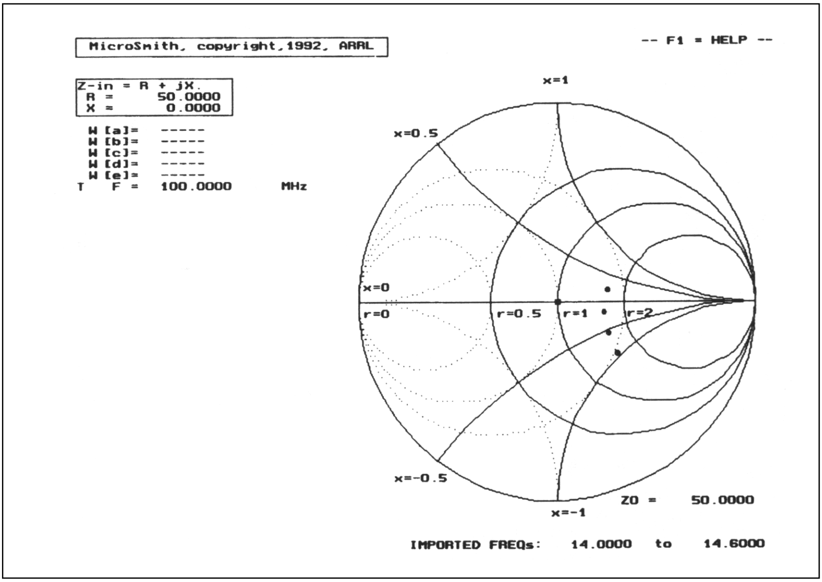

Fig 8-2—50-Ω Smith Chart display showing the backyard dipole impedance data calculated with ELNEC. Data points are listed in Table 8-1.

A SPICE Example

Generating data from a SPICE output file is straightforward. First describe the circuit of interest in a SPICE net list. Include suitable voltage sources and a source resistor to generate a reflection coefficient. (See the

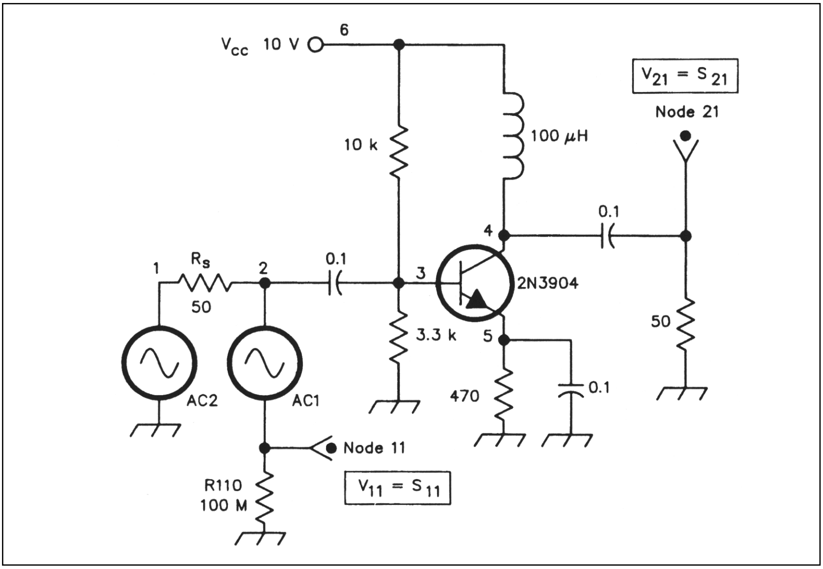

Fig 8-3—Circuit used for the SPICE program example discussed in the text. SPICE calculates the input reflection coefficient of the small-signal 2N3904 amplifier. Resistances are in ohms; k = 1000. Capacitances are in picofarads.

example that follows.) Perform an AC sweep to cover the frequencies of interest. Include a print statement that requests printing of the voltage and the related phase representing the reflection coefficient. The result will be a disk file containing the SPICE output. The file must be edited. Virtually all of the information is to be removed. Keep only the frequency, voltage magnitude, and voltage phase data. You must insert a number at the beginning of the file representing the characteristic impedance used to define the reflection coefficient. Be sure to get rid of any text or stray numeric information. After editing, rename the file. The new name should have a GAM extension.

A sample of such a SPICE run is included with *MicroSmith*. Three companion files are supplied. The SPICE input file is named AMP3904.CIR. This is a simple, one-stage wide-band amplifier using a 2N3904 transistor. The circuit diagram is shown in Fig 8-3. In the input circuit a pair of generators are present. V_{in} is a 2-volt ac source that drives a 50-Ω source resistance, R_s. A second generator interconnects node 2 to node 11. That generator has a 1-volt amplitude. The voltage at node 11 is the reflection coefficient looking into the amplifier. Specifically, V (11) = S_{11}, the input scattering parameter. Although not used here, the forward-gain scattering parameter, S_{22}, is available at node 21. The output and reverse scattering parameters, S_{22} and S_{12}, are obtained by terminating the input and driving the output with the same "network analyzer" circuit.

The second disk file is named SPICE.GAM. This is the output file that has been modified for reading by *MicroSmith*. Note that the form is rather sloppy. This illustrates the freedom afforded by a "text" file format. However, just one number that is out of sequence will do unpredictable things to the results!

When SPICE.GAM is loaded into *MicroSmith* (**F6 D** SPICE **Enter 0 Enter**), a series of 15 reflection coefficients is in place, covering the 10 to 150-MHz range. Display the data on the chart with **Alt-G**. The input impedance is dominated by capacitance, and this is expected. You can model the 2N3904 input as a parallel R-C circuit with a small series R. Such a model is contained in the file called SPIC3904.DAT. Load this circuit model by pressing **Alt-R** and entering the filename. A frequency sweep from 10 to 150 MHz is included.

The parallel R-C is the so-called hybrid-pi capacitance and resistance. The series R is the base spreading resistance. You can compare the model and the actual impedance data by pressing **F5** and then **Alt-G**. These three files illustrate some of the power of SPICE. Specifically, the simple linear models so often used are an integral part of the more complicated, nonlinear models featured in SPICE.

Using Swept Frequency Terminations

Probably the most powerful feature of *MicroSmith* is its swept-frequency capabilities. That is, the frequency may be varied in the same way that any component value can be tuned or swept. Most simple applications use a simple impedance to terminate a network. The typical "load" in such applications is a complex impedance that does not vary with frequency. While this simplifies analysis, it is not a real-world situation. The true terminating impedance is typically a frequency-dependent parameter. ARRL *MicroSmith* will analyze circuits having this characteristic.

Enter a complex, frequency-dependent termination from the *MicroSmith* Schematic Editor. Begin by pressing **G** or **L** to enter a termination as either a gamma value or a complex impedance. For just one termination value, press **Enter**. For a frequency-dependent termination, specify a number greater than 1 to indicate how many frequencies you will enter.

After you enter the number of frequencies, you will be asked for the mode of data entry. You may enter data in either complex, polar Γ form or as a complex impedance, $Z = R + jX$. Up to 9 frequencies are allowed for a wide-band termination. A table of default F values is presented when a frequency-dependent termination is to be used. The individual points may then be edited In the editing mode, a polar Γ or a complex impedance may be entered. Impedance values are converted to Γ form.

The data that you enter should be presented in ascending frequency order. That is, point no. 1 should be the lowest frequency, and so on. At intermediate frequencies, *MicroSmith* will linearly interpolate the frequency-versus-impedance characteristics.

Important Note for Frequency Sweeps

Termination frequencies should bracket all *MicroSmith* frequency Sweep ranges. For example, assume that you want to match a wide-band amplifier from 3 to 30 MHz. You specify a frequency sweep over this range for stepping and sweeping. For the frequency-dependent termination, it would be realistic to specify 5 or 6 impedance points from 3 to 30 MHz. To bracket the Sweep range, you should define the termination frequency range as something slightly greater than 3 to 30, such as from 2.999 to 30.001 MHz. Problems and inaccuracies may be encountered in an analysis if the Sweep range you specify equals the lower and upper termination frequencies.

Frequency Sweeping A Dipole Antenna

The following dipole antenna example illustrates *MicroSmith*'s powerful frequency-dependent termination capabilities. This analysis represents a common *MicroSmith* application for radio amateurs. Assume you are considering a dipole antenna for 7 and 21-MHz operation. You plan to make the antenna 68 feet long and install it at a height of 40 feet. With ELNEC you analyze the dipole as a horizontal wire above real earth, at both 7 and 21 MHz. The impedance match is reasonable on both bands, although less than spectacular. ELNEC provides impedance data for both frequencies. You convert these impedances to reflection-coefficient values with *MicroSmith* and enter the resulting values as the termination.

To save you the trouble of actually performing the steps outlined in the preceding paragraph, the file DIP721.DAT has been created for you. Load the file into the program with **Alt-R**. You can review the reflection-coefficient values from the Schematic Editor by pressing **G**, followed by two carriage returns. The sweep is set up to include only two points, 7 and 21 MHz.

The file DIP721 includes an L network. This circuit has been adjusted with *MicroSmith* to provide a good impedance match to 50 Ω at 21 MHz. The network has little impact at the lower frequency. The impedances available without the matching network are easily evaluated by editing.

Simply change the L-network components to wires.

It is possible to obtain a near-perfect match at both frequencies with a four-element network consisting of cascaded low-pass and high-pass L networks. The two-element network shown is probably the more practical solution.

One may be tempted to increase the sweep resolution, stepping in increments of 0.5 MHz, for example, instead of the large one used. This will not provide meaningful data unless some intermediate frequencies are included within the data set for the termination.

Frequency Sweeping a Vertical Antenna

This example considers another classic antenna, a 34-foot vertical antenna built with 1-inch-diameter pipe. This antenna was analyzed with ELNEC using real earth, and the results are contained in the file named VERT34FT.DAT. The feed-point impedance was calculated for this structure at 7, 10.1, 14, 18.1 and 21 MHz. The circuit of VERT34FT.DAT contains no matching network, but includes a sweep from 7 to 21 MHz in 0.1-MHz steps. The resulting curve (press **F5** after calling VERT34FT with **Alt-R**) is generally smooth. Slope discontinuities are noted at 14 and 18 MHz.

The impedance match is reasonable for this antenna at both frequency extremes, but is poor at the mid-frequency range. The antenna may be matched with an L network of one type or another at any frequency within the 7 to 21-MHz range. Unfortunately, a match at one frequency will generally degrade the match at others.

The file named VERT714.DAT contains a two-band solution. The desired result was a good impedance match at both 7 and 14 MHz. The terminating impedance data was not changed. The sweep was altered, however, to include only the two end points—7 and 14 MHz. A good match can be realized at 14 MHz with a low-pass L network, but the 7-MHz match is very poor. The three-element network in VERT714 provides an excellent match at 14 MHz, with a reasonable one at 7 MHz.

You can see the effects of adjusting this network with *MicroSmith* by using the Step and Sweep mode. The Sweep controls frequency. Select the tuning elements, one at a time, and step them with the **+** and **–** keys.

The two-frequency Sweep shows the match at the two frequencies. It is interesting to change the Sweep to one with high resolution. While the impedance match is well behaved at 7 and 14 MHz, it becomes very poor at the 10-MHz mid-frequency area.

Chapter 9

MicroSmith, Version 2.3

A major upgrade of *MicroSmith*, Version 2.3, was completed in late 1996 and features the following changes:

1. Rectangular plots of Gamma and VSWR are added to supplement the Smith Chart plots. The rectangular plots can also include user-entered VSWR data.

2. A new construct, termed "depth," is added to the program. This allows the user to quickly see the impedances available at any plane in the matching network, including the impedance before any matching has occurred.

3. Recognizing that few users continue to use 9-pin dot matrix printers, the printing capabilities contained in earlier versions have been eliminated. Instead, printing in Version 2.3 occurs through the DOS program Graphics.COM, or through Windows. The user must have DOS Version 5.0 or later, Windows Version 3.1, Windows 95, or Windows NT for this printing. These structures allow virtually any printer to function with *MicroSmith*.

The Version 2.3 features described in this chapter also apply to Version 2.4, which was compiled for inclusion with *Introduction to Radio Frequency Design.*

This chapter begins with installation details for Version 2.3. It then examines the new features and illustrates them with examples. Finally, printing from DOS and from Windows is discussed, including hints for running *MicroSmith* from the Windows environment.

Rectangular Plots in *MicroSmith*

The utility of the Smith Chart lies in simultaneously presenting impedance magnitude and angle information. However, we often use simpler forms when dealing with real data. An especially useful plot for antenna evaluations shows reflection coefficient or VSWR vs. frequency, a subset of the data that is often included in a Smith Plot.

Rectangular plots relate to **swept** data, which was presented in Chapter 5. Sweep data was entered from the schematic display, which was activated with **F9**, followed by **S**. Once back in the Smith Chart mode, a sweep is seen on the chart by pressing **F5**. Pressing **Alt-F5** shows sweep parameters. The new feature, a rectangular plot, occurs when **Ctrl-F5** is pressed. This generates a graph in a window that covers part of the Smith Chart. The plot is one of Gamma magnitude (reflection coefficient) vs.

whatever the swept parameter might be. If a sweep had not been set up, nothing appears with **Ctrl-F5**. The plot is labeled with both Gamma and VSWR lines.

Figure 9.1 shows a plot of Gamma and VSWR vs. swept frequency for a quarter wavelength (7 MHz) vertical antenna. The dots show the match of the antenna without a matching network. The solid curve shows the match after a special dual-band matching network has been added, providing a good match at both 7 and 14 MHz.

The rectangular plot has the X-axis labeled with the extremes of the swept parameter. It is not necessary that the variable be frequency. It could just as well be a component value. Tuning is not supported from the rectangular plot.

Pressing **M** from a VSWR plot causes two frequencies to be marked. The related values are printed below the X-axis. The frequency values are set up when the sweep is established with **F9** and **S**, and functions only if the independent variable is frequency. The marker frequencies must lie within the sweep window.

Pressing **D** while viewing the rectangular plot will cause data plots to

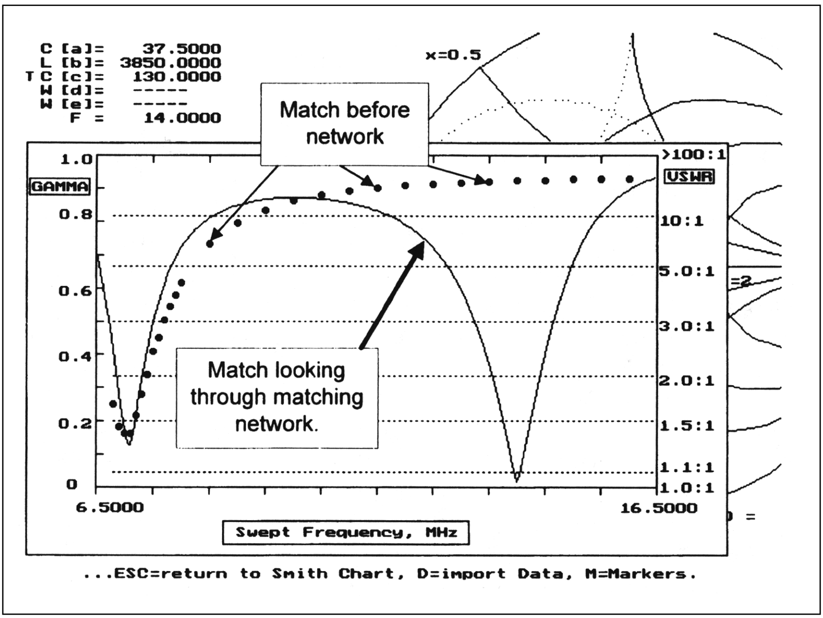

Fig 9-1—A rectangular plot of VSWR vs. frequency for a 34-foot vertical antenna. This example is on the disk as TWOBAND.DAT while the unmatched data is in the file RAWVERT.GAM.

be printed on the chart. This data is obtained from a file with an extension of "gam." These files have been covered elsewhere in this manual. See "Moving Data into *MicroSmith*" in Chapter 8. The rectangular plot has no phase information. However, when building a GAM file, something (such as 0) must be included in the file. The GAM files may be built within *MicroSmith* after pressing **F6**.

Displaying data from a GAM file should be especially useful when measured data is compared with calculations.

"Depth" in *MicroSmith*

A new idea, termed "depth," was introduced in Version 2.3 of *MicroSmith*. The depth parameter indicates the impedance plane investigated by *MicroSmith*. The depth parameter is printed in the upper right corner of the Smith Chart display with a default value of 5, indicating that all 5 elements in the network are included in the calculations. The schematic display (**F9**) for *MicroSmith* Version 2.3 has the various planes marked with the corresponding depth.

Shifting from one depth to another is accomplished by pressing a numeral from 0 to 5 while viewing the Chart. Consider an example, the vertical antenna used for a previous example. When the file is loaded (TWOBAND.DAT) with **Alt-R**, the depth is 5, indicating that the entire network is considered during impedance calculations. Pressing **F5** generates a sweep showing two regions of resonance, one at 7 and the other at 14 MHz. Pressing **0** eliminates the entire network. Pressing **F5** now shows the behavior of the basic antenna without modification by the network. Pressing **1** will show the effect of adding the first element, a parallel capacitance, but nothing more. The network elements can be added, one at a time, showing the results for each network *depth*.